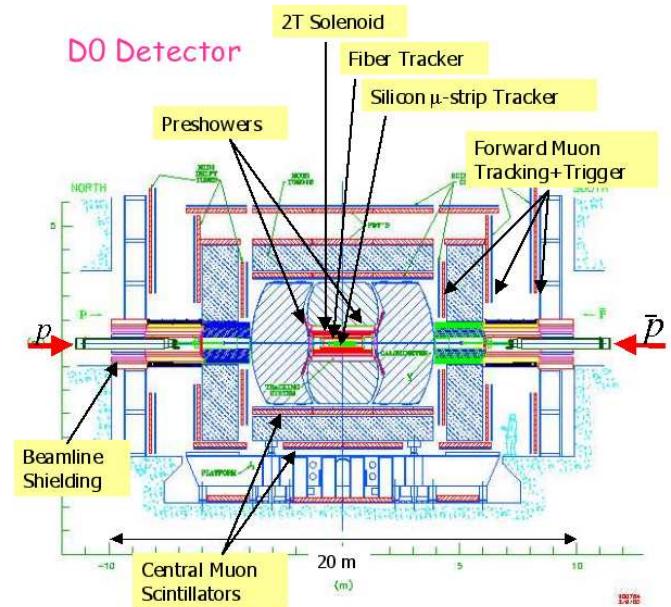


B_s -Flavor Tagging at D \emptyset



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St. Louis, Missouri



<http://www-d0.fnal.gov/~rakinin/APS08.pdf>

B_s -Flavor Tagging

- Challenging task in B -physics: to determine (tag) B_s meson production flavor which may be different from decay flavor

- Needed for:
 - B_s mixing [DØ Note 5474]
 - CP violation [hep-ex/0802.2255]

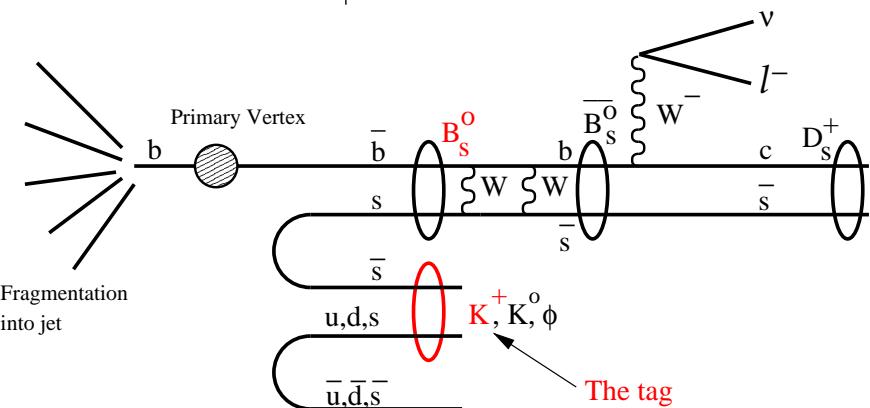
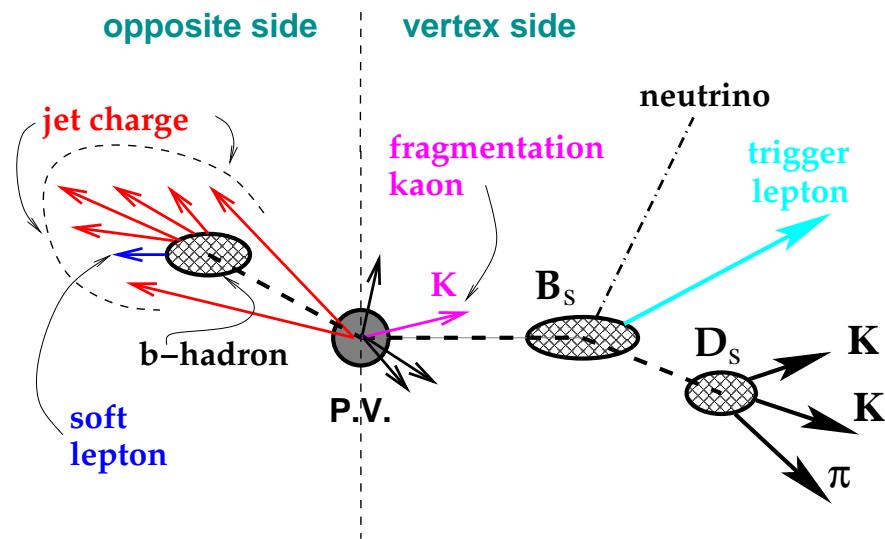
- Two main classes of tagging methods:

☞ **Same-Side Tagging:**

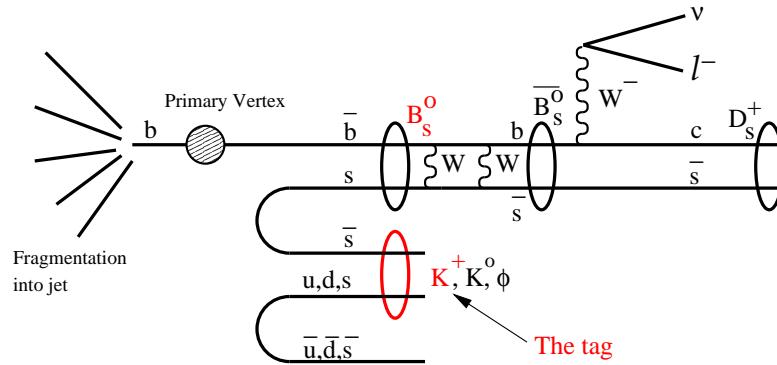
“One-track”, Q_{SST} ...

☞ **Opposite-Side Tagging:**

jet-charge, soft-lepton, Q_{OST} ...



Tagging characteristics:



- Number of Right-Sign ($B_s - K^+$ and $\overline{B}_s - K^-$) correlations, N_{RS}
- Number of mistagged Wrong-Sign (e.g., $B_s - K^-$ and $\overline{B}_s - K^+$) correlations, N_{WS}
- Number of events with no tag found, N_{NT}
- Tagging efficiency $\epsilon = \frac{N_{tagged}}{N_{total}} = \frac{N_{RS} + N_{WS}}{N_{RS} + N_{WS} + N_{NT}}$
and dilution $D = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$
- Tagging power $\epsilon D^2 \Leftarrow$ to be maximized
 - It can be shown that error on B_s -mixing parameter is $\sim \frac{1}{\sqrt{\epsilon D^2}}$

Monte Carlo and Data

- SST:

- \Bbbk B_s production flavor is obtained from MC truth information
- \Bbbk SST analysis can only be done on MC: e.g. $B_s \rightarrow \nu_\mu \mu D_s$ or $B_s \rightarrow J/\psi \phi$
- \Bbbk SST can be verified on self-tagging $B_u \rightarrow J/\psi K$ sample
 - B_u flavor is determined from kaon charge \implies can be determined in both data and MC
 - The agreement between dilutions in data and MC is good which justifies using SST in B_s decays

- OST:

- \Bbbk Opposite-side flavor tagging does not depend on the B -meson flavor
- \Bbbk Can use $B_d \rightarrow \nu_\mu \mu D^{*-}$ data sample to develop OST for B_s [PRD74, 112002 (2006)]

Let's first talk about SST only



SST Algorithms

All used SST algorithms can be divided into two groups:

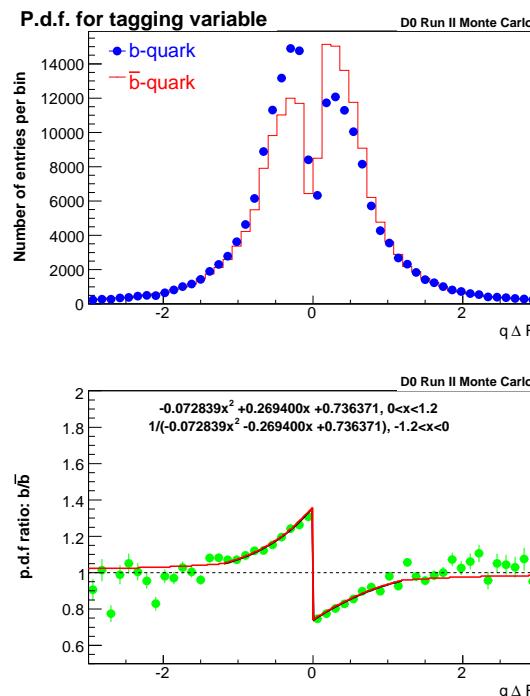
1. **One-track algorithms** which select a particular track and infer b -quark flavor from its charge
2. **Many-track algorithms** which use p_t -weighted average charge of all tracks around $\vec{p}(B_s)$: $Q_{SST}(p_t, \kappa) = \frac{\sum q \cdot p_t^\kappa}{\sum p_t^\kappa}$

- Often different one-track taggers pick up the same track \Rightarrow highly correlated
- Let's pick the best tagger from each group
- Best one-track tagger: “Min. $\Delta R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$ ”
- Best many-track tagger: $Q_{SST}(p_t, \kappa = 0.6)$ ”
- Let's combine both these taggers together to improve ϵD^2

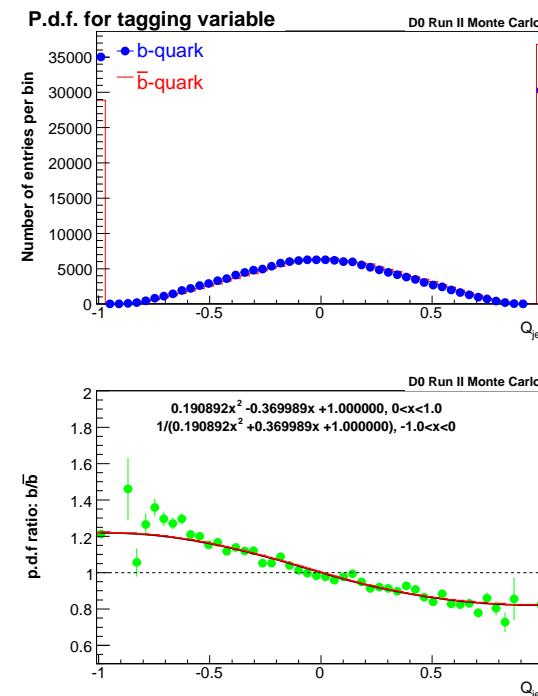
Combination of two SST methods

- We obtain P.D.F.s of “ $q \cdot \Delta R$ ” for “Min. ΔR ” tracks with charge q for b and \bar{b} quarks
- If their ratio $y_{\Delta R} = \frac{f(b)}{f(\bar{b})} > 1$ then it was b -quark, otherwise \bar{b} -quark
- Calculate “joint P.D.F. ratio” for “Min. ΔR ” and $Q_{SST}(p_t, \kappa = 0.6)$ taggers: $y_{sst} = y_{\Delta R} \cdot y_Q$
- Introduce a variable $d_{sst} = \frac{1-y_{sst}}{1+y_{sst}}$ and determine b -quark flavor for each event from its sign
- Calculate even-by-event dilution D as a function of d_{sst}

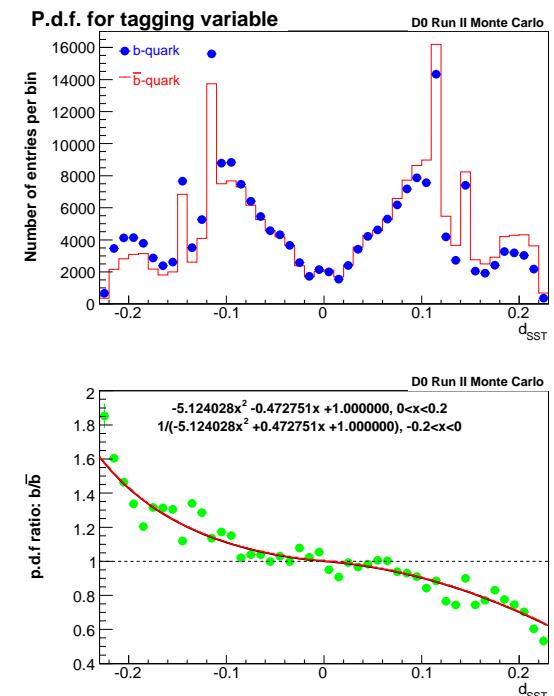
“Min. ΔR ” P.D.F.s



$Q_{SST}(p_t, \kappa = 0.6)$ P.D.F.s



“Joint P.D.F.s”





ϵD^2 for combined SST



| MC | Tagger | ϵ , % | D , % | "Unbinned" ϵD^2 , % | "Binned" ϵD^2 , % |
|---|-------------------------|----------------|----------------|-------------------------------|-----------------------------|
| $B_u \rightarrow J/\psi K B_u \rightarrow J/\psi K$ data | "Min. ΔR " | 82.1 ± 1.1 | 20.2 ± 0.7 | 3.34 ± 0.22 | 3.73 ± 0.24 |
| | " $Q_{jet}(p_t, 0.6)$ " | 88.4 ± 1.2 | 19.3 ± 0.6 | 3.28 ± 0.22 | 4.06 ± 0.24 |
| | "Comb. SST" | 88.4 ± 1.2 | 19.0 ± 0.6 | 3.19 ± 0.22 | 4.81 ± 0.26 |
| $B_u \rightarrow J/\psi K B_s \rightarrow \mu D_s(\phi\pi)$ Monte Carlo | "Min. ΔR " | 79.2 ± 0.5 | 18.6 ± 0.5 | 2.74 ± 0.15 | 2.82 ± 0.15 |
| | " $Q_{jet}(p_t, 0.6)$ " | 89.0 ± 0.6 | 19.6 ± 0.5 | 3.43 ± 0.17 | 3.92 ± 0.17 |
| | "Comb. SST" | 89.1 ± 0.6 | 17.8 ± 0.5 | 2.82 ± 0.15 | 4.02 ± 0.17 |
| $B_s \rightarrow J/\psi \phi B_s \rightarrow \mu D_s(\phi\pi)$ Monte Carlo | "Min. ΔR " | 84.9 ± 0.6 | 14.8 ± 0.5 | 1.86 ± 0.14 | 1.96 ± 0.14 |
| | " $Q_{jet}(p_t, 0.6)$ " | 93.0 ± 0.7 | 13.9 ± 0.5 | 1.80 ± 0.14 | 2.25 ± 0.15 |
| | "Comb. SST" | 93.0 ± 0.7 | 14.2 ± 0.5 | 1.86 ± 0.14 | 2.49 ± 0.16 |
| $B_s \rightarrow J/\psi \phi B_s \rightarrow \mu D_s(\phi\pi)$ Monte Carlo | "Min. ΔR " | 78.7 ± 0.7 | 13.4 ± 0.7 | 1.41 ± 0.14 | 1.57 ± 0.15 |
| | " $Q_{jet}(p_t, 0.6)$ " | 81.5 ± 0.7 | 13.8 ± 0.6 | 1.55 ± 0.15 | 1.84 ± 0.16 |
| | "Comb. SST" | 81.5 ± 0.7 | 13.1 ± 0.6 | 1.40 ± 0.14 | 2.01 ± 0.16 |

- "Unbinned" ϵD^2 is a direct product of ϵ and D^2
- "Binned" ϵD^2 is a sum of ϵD^2 's in $|d|$ bins
- We see some improvement in "binned" ϵD^2 due to SST combination for all decay signatures



OST/Event Charge



- OST was developed on $B_d \rightarrow \mu D^*$ data sample [**PRD74**, 112002 (2006)]
- Must be the same for B_d and B_s
- Also, a combination of a few taggers:
 - soft muon
 - soft electron
 - secondary-vertex
- Unfortunately, OST above has low efficiency
- When OST is not present, we use Event Charge (Q_{OST}) obtained as p_t -weighted $\sum q_i$ of all tracks on opposite side
- Event Charge has 100% tagging efficiency, but lower dilution



ϵD^2 for SST + OST/EvtCh

- SST + OST/Event Charge are also combined using P.D.F.s

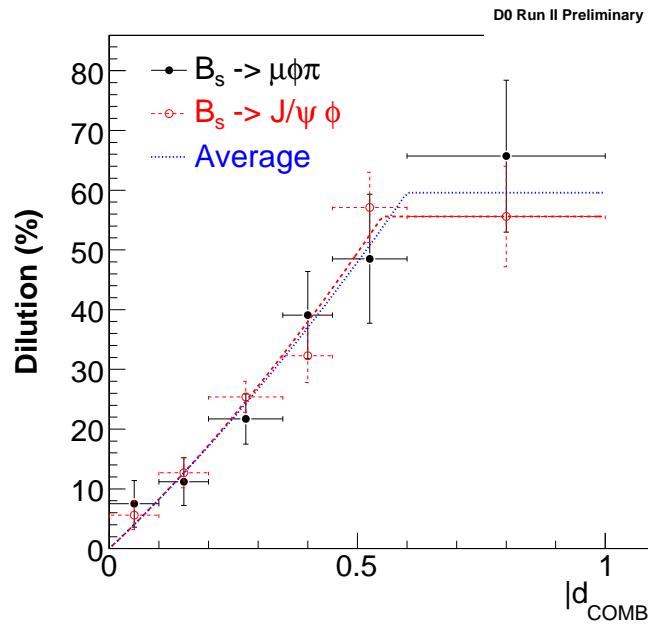
| Sample | Tagger | ϵ , % | D , % | Unbinned ϵD^2 , % | Binned ϵD^2 , % |
|---|----------------|-----------------|----------------|-----------------------------|---------------------------|
| $B_u \rightarrow J/\psi K$ data | "Comb. SST" | 89.1 ± 0.6 | 17.8 ± 0.5 | 2.82 ± 0.15 | 4.02 ± 0.17 |
| | "Comb. OST" | 18.3 ± 0.2 | 22.2 ± 1.1 | 0.90 ± 0.09 | 1.26 ± 0.09 |
| | "Event Charge" | 99.9 ± 0.6 | 10.3 ± 0.5 | 1.06 ± 0.09 | 1.31 ± 0.10 |
| | "All" | 100.0 ± 0.6 | 18.3 ± 0.5 | 3.33 ± 0.17 | 4.76 ± 0.18 |
| $B_u \rightarrow J/\psi K$ data | "Comb. SST" | 88.4 ± 1.2 | 19.0 ± 0.6 | 3.19 ± 0.22 | 4.81 ± 0.26 |
| | "Comb. OST" | 16.9 ± 0.3 | 26.8 ± 1.4 | 1.21 ± 0.13 | 1.91 ± 0.15 |
| | "Event Charge" | 100.0 ± 1.3 | 9.8 ± 0.6 | 0.97 ± 0.12 | 1.36 ± 0.14 |
| | "All" | 100.0 ± 1.3 | 18.9 ± 0.6 | 3.58 ± 0.23 | 5.79 ± 0.27 |
| $B_s \rightarrow \mu D_s(\phi\pi)$ Monte Carlo | "Comb. SST" | 93.0 ± 0.7 | 14.2 ± 0.5 | 1.86 ± 0.14 | 2.49 ± 0.16 |
| | "Comb. OST" | 25.4 ± 0.3 | 23.2 ± 1.0 | 1.37 ± 0.12 | 2.02 ± 0.13 |
| | "Event Charge" | 99.9 ± 0.7 | 6.9 ± 0.5 | 0.48 ± 0.07 | 0.78 ± 0.09 |
| | "All" | 100.0 ± 0.7 | 14.8 ± 0.5 | 2.20 ± 0.15 | 3.86 ± 0.19 |
| $B_s \rightarrow J/\psi \phi$ Monte Carlo | "Comb. SST" | 81.5 ± 0.7 | 13.1 ± 0.6 | 1.40 ± 0.14 | 2.01 ± 0.16 |
| | "Comb. OST" | 24.4 ± 0.3 | 27.6 ± 1.1 | 1.86 ± 0.16 | 2.70 ± 0.17 |
| | "Event Charge" | 98.3 ± 0.8 | 9.3 ± 0.6 | 0.84 ± 0.11 | 1.24 ± 0.13 |
| | "All" | 98.3 ± 0.8 | 15.7 ± 0.6 | 2.43 ± 0.18 | 4.43 ± 0.23 |

- Tagging power ϵD^2 grows as a result of combination
- Combined tagging power for both B_s decay modes is $(4.09 \pm 0.14)\%$

Calibration curves

To obtain event-by-event dilution for B_s we:

- plot $D(d_{comb})$ dependence for $B_s \rightarrow \mu D_s(\phi\pi)$ Monte Carlo (black)
- plot $D(d_{comb})$ dependence for $B_s \rightarrow J/\psi\phi$ Monte Carlo (red)
- obtain weighted-average points from both plots (SST fragmentation does not depend on the B_s decay mode)
- fit them with parabola + constant (blue)



Dilution grows as $|d_{comb}|$ grows, quite close to ideal case $D = 100\% \cdot |d_{comb}|$

Conclusion

- SST works for $B_u \rightarrow J/\psi K$ (data and MC) $B_s \rightarrow \mu D_s(\phi\pi)$ (MC) and $B_s \rightarrow J/\psi\phi$ (MC)
- Combination of two SST algorithms ("Min. ΔR " and " $Q_{jet}(p_t, \kappa = 0.6)$ ") increases total ϵD^2 compared to individual ϵD^2 's
- Combination SST + OST/Event Charge also increases total ϵD^2 compared to individual ϵD^2 's
- Combined flavor tagging power in DØ is quite high: $(4.09 \pm 0.14)\%$
- Event-by-event dilution (calibration curve) is obtained
- The method is already applied to B_s mixing measurement [DØ Conf. Note 5474] and to CP violation studies [hep-ex/0802.2255]
 - ☞ Addition of SST increases B_s mixing parameter sensitivity by 23.6%

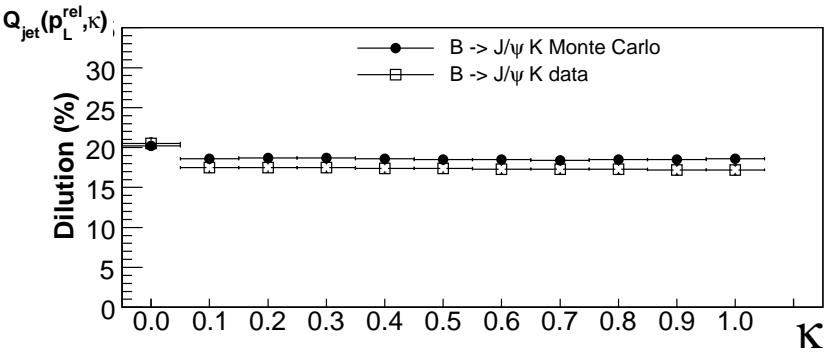
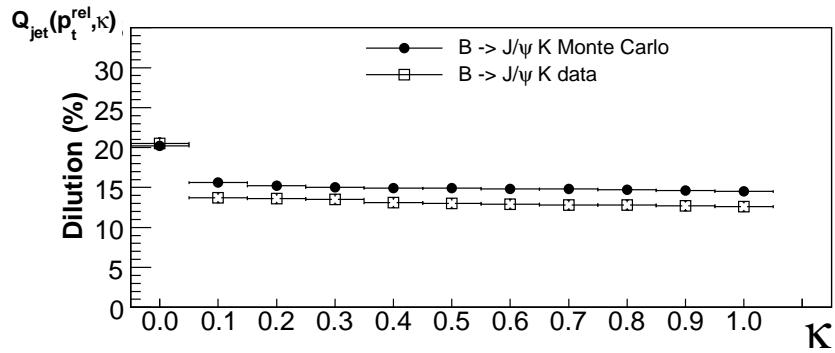
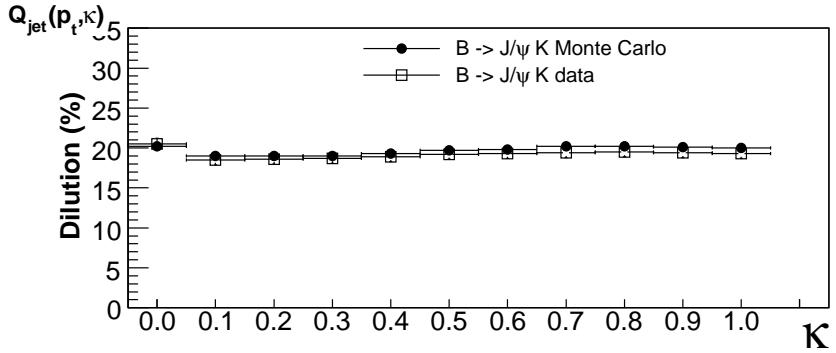
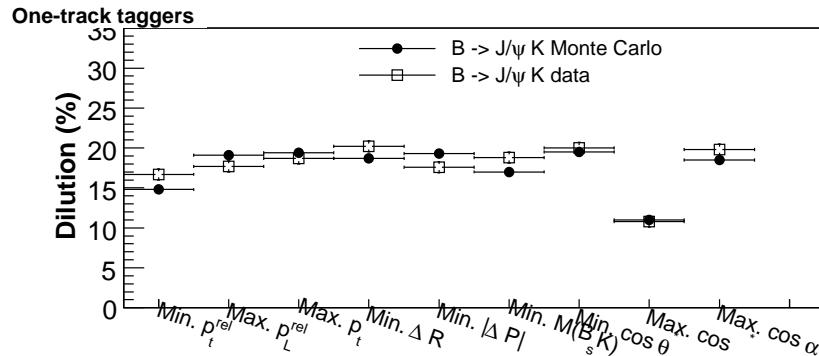


Backup



SST verification on data/MC

Good data–MC match for dilutions for different taggers for $B_u \rightarrow J/\psi K$ decay:



Conclusion: SST works for both data and MC, gives $D = 15 – 20\%$

- Best one-track tagger: “Min. ΔR ”
- Best many-track tagger: “ $Q_{SST}(p_t, \kappa = 0.6)$ ” (for consistency with previously developed OST)

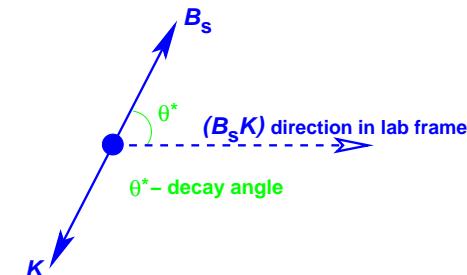
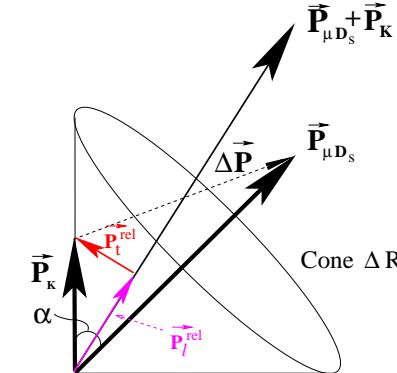
List of used same-side taggers:

- Use the following SSTs (one-track and many-track taggers)
- Taggers in each group are highly correlated – choose one representative from each group

- ☞ Min. p_t^{rel}
- ☞ Max. p_L^{rel}
- ☞ Max. p_t
- ☞ Min. $|\Delta\vec{P}| \equiv |\vec{p}(B_s) - \vec{p}(K)|$
- ☞ Best: Min. ΔR
- ☞ Min. $\cos\theta^*$
- ☞ Max. $\cos\theta^*$
- ☞ Min. $m(B_s K)$
- ☞ Max. $\cos\alpha$

- ☞ $Q_{SST}(p_t, \kappa) = \frac{\sum q \cdot p_t^\kappa}{\sum p_t^\kappa}$
- ☞ $Q_{SST}(p_t^{\text{rel}}, \kappa) = \frac{\sum q \cdot (p_t^{\text{rel}})^\kappa}{\sum (p_t^{\text{rel}})^\kappa}$
- ☞ $Q_{SST}(p_L^{\text{rel}}, \kappa) = \frac{\sum q \cdot (p_L^{\text{rel}})^\kappa}{\sum (p_L^{\text{rel}})^\kappa}$
- ☞ Best: $Q_{SST}(p_t, \kappa = 0.6)$

- One-track: p_t^{rel} and p_L^{rel} are \perp and \parallel components of SST candidate's momentum $\vec{p}(K)$ w.r.t $\vec{p}(B_s K)$
- $\Delta R \equiv \sqrt{\Delta\phi^2 + \Delta\eta^2}$ and angle α are taken between $\vec{p}(B_s)$ and $\vec{p}(K)$
- θ^* – decay angle of $B_s K$ -system, i.e. angle between directions of $\vec{p}(B_s K)$ and $\vec{p}(B_s)$ in reference frame of $B_s K$ system
- $\kappa = 0.0, 0.1, 0.2, \dots 1.0$
- Q_{SST} : p_t^{rel} and p_L^{rel} are \perp and \parallel components of SST candidate's momentum $\vec{p}(K)$ w.r.t $\vec{p}(B_s)$





Combination SST + OST/EvtCh



- Same combination technique as for SST
- If OST present make “joint P.D.F.” $y_{comb} = y_{sst} \cdot y_{ost}$
- If OST not present take $y_{comb} = y_{sst} \cdot y_{evtch}$
- Introduce variable $d_{comb} = \frac{1-y_{comb}}{1+y_{comb}}$
- Infer b -quark production flavor from sign of d_{comb}
- Obtain event-by-event dilution with function $D(d_{comb})$